Microquasar hadronic jets at very high-energy gamma-rays

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Microquasars (MQs) present emission over the whole spectrum, from radio wavelengths to gamma-rays. The microquasar spectral energy distribution is very complex, being a signature of the different physical processes that generate the radiation emitted by these objects. In this work, we estimate the amount of broad-band emission produced by relativistic protons, released from the jet of a MQ, interacting with high density regions of the ISM. We show that a two components source, the microquasar itself and the region of interaction between the jets and the ISM, could be unveiled by the new instruments at high-energy and very high-energy gamma-rays.

1 Introduction

The likely association between microquasars and gamma-ray sources ([1]), altogether with the evidence of ion presence in MQ jets ([2]), might point to the possibility that these objects could produce variable and point-like as well as steady and perhaps extended gamma-ray emission. On the one hand, the radiation coming from the microquasar itself, particularly from its jets (likely variable and point-like), could reach very high energies and significant fluxes. The emission produced in the jets of MQs has been studied elsewhere, and leptonic models (e.g. [3]) and hadronic models (e.g. [4]) have been proposed in order to explain the likely association between microquasars and gamma-ray sources. On the other hand, accelerated protons in a jet termination shock could diffuse through the ISM generating detectable amounts of low energy as well as high energy emission (steady and perhaps extended) when these protons reach higher density regions (i.e. clouds).

2 MQ-cloud interactions and gamma-ray production

Jets of MQs should end somewhere, although it is still unclear the way how they terminate ([5], [6]). Assuming that the jet has an important population of protons and such protons are accelerated in the terminal part of the jet (getting a power-law energy distribution), interactions between those high energy particles and nearby clouds can lead to the creation of neutral and charged pions. Then, neutral pions will decay to gamma-rays photons while charged pions will

Parameter	Value
diffusion coefficient normalization constant at 10 GeV	10^{27} cm^2 s^{-1}
diffusion power-law index	0.5
ISM density	0.1 cm^{-3}
cloud density	10^4 cm^{-3}
mass of the high density region/cloud	$3 \times 10^4\ M_\odot$
magnetic field within the cloud	5×10^{-4} G
IR radiation energy density within the cloud	10 eV cm^{-3}
power-law index of the high energy protons	~ 2
maximum energy of the high energy protons	$\sim 10^5$ GeV
kinetic luminosity of accelerated protons in the MQ jet	10^{37} erg s^{-1}
kinetic energy of accelerated protons in the impulsive ejection	10^{48} erg
distance between the MQ and the cloud	10 pc

Table 1: Adopted parameter values

decay to e$^-$ and e$^+$. These secondary particles can produce significant levels of synchrotron (from radio frequencies to X-rays) and Bremsstrhlung emission (from soft gamma-rays to the TeV range), and generally with much less efficiency, inverse Compton high energy emission through interaction with the ambient infrared photons. For further details, see [7].

Protons diffuse through the ISM, and the diffusion coefficient has been assumed to be a power-law in energy. Due to propagation effects, the outcomes of the interactions between the protons released from the jet and protons in the clouds can differ strongly depending on the age, the nature (impulsive or continuous) of the accelerator and the distance between this and the cloud (see [8]). In this work we study both cases, the continuous and the impulsive one, considering as a target a nearby cloud at several pc of distance. In Table 1, the adopted parameter values are presented. We note that in the gamma-ray band, due to the characteristics of the proton-proton interaction, the main energy release channel is the neutral pion-decay, being dominant over the Bremsstrählung component. In Figs. 1 and 2, the broad-band spectral energy distributions (SEDs) for the impulsive and the continuous case are shown. Note the different slopes and fluxes depending on the case. For a continuous MQ, the spectrum reaches higher luminosities ,and gets softer, when the source is "old" and gets the steady regime. For a continuous MQ, The higher luminosities, with a hard spectrum, can be observed when the source is "young".

Although the number of known MQs is reduced at the present moment (about 16, see [9], [10]), they could be a significant fraction of the unidentified gamma-ray sources in the galactic plane ([3]). If this association as well as their intrinsic nature of gamma-ray emitters are confirmed, these objects could turn out to be complex sources in the gamma-ray sky with compounded spatial and spectral properties at very high energies. Our bet is that, if observed with reasonable exposure times at high-energy and very high-energy gamma-rays, MQs will be eventually detected. Otherwise, the existence of steady and perhaps extended gamma-ray radiation surrounding a variable point-like gamma-ray source could be a strong hint of the presence of a MQ interacting with its environment and, in such a case, multiwavelength

observations would be unavoidable to disentangle the real nature and connections between both components, and broad-band spectrum models like the one presented here can help to understand them.

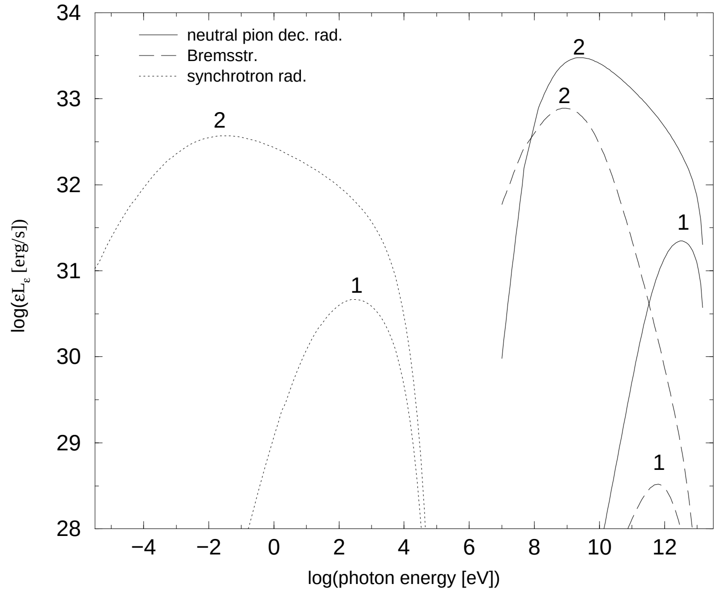

Figure 1: SED for a continuous MQ from radio to vcry high-energy gamma-rays at two different ages: t=100 yr (1), t=10000 yr (2). Note that the source could be detected almost at all the frequencies if located at galactic distances.

3 Summary

The study of the emission coming from high density regions of the ISM around MQs can give us information not only about such regions, but also about the objects that are injecting energy in those regions through high energy protons. In this work, we explored the observational implications at very high energies of the presence of a MQ close to a cloud. New gamma-ray instruments like the ground-based Cherenkov telescopes or the next generation of gamma-ray satellites could be able to detect separately the emission coming from a MQ and the region around, if significant hadronic interactions take place there.

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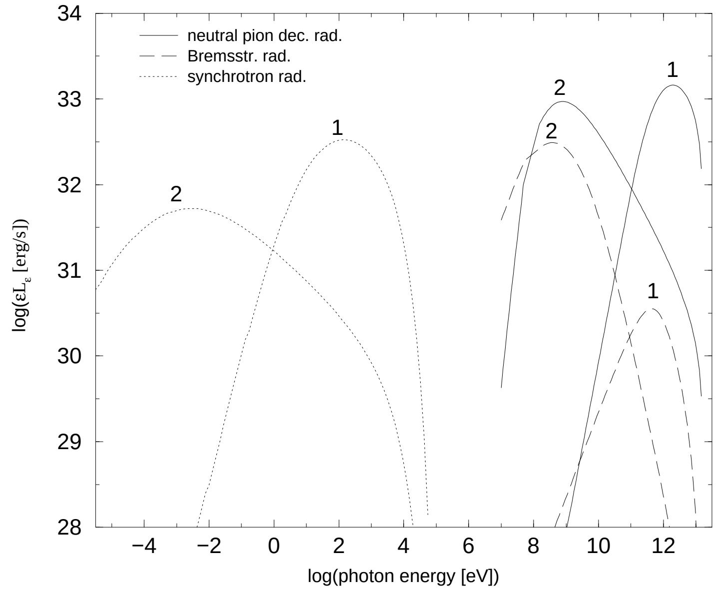

Figure 2: The same as in Fig. 1, but for an impulsive microquasar. Note that the detection would be more probable for short times after the impulsive event.

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